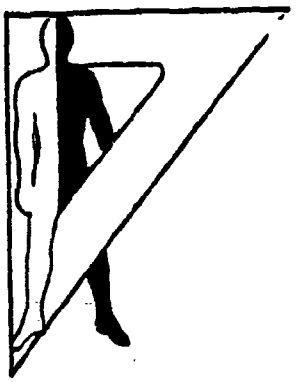

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Technical Memorandum 11-90

THE EFFECTS OF SPEECH INTELLIGIBILITY ON CREW PERFORMANCE IN AN M1A1 TANK SIMULATOR

Leslie J. Peters
Georges R. Garinther

October 1990
AMCMS Code 611102.74A0011

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U.S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): Technical Memorandum 11-90	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Human Engineering Laboratory; 6b. OFFICE SYMBOL (If applicable): SLCHE	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Aberdeen Proving Ground, MD 21005-5001	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 6.11.02; PROJECT NO. 1L161102B74A; TASK NO.; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
The Effects of Speech Intelligibility on Crew Performance in an M1A1 Tank Simulator

12. PERSONAL AUTHOR(S)
Peters, L. J., Garinther, G. R.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM _____ TO _____	1990, October	72

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	armor crew performance; communication; speech intelligibility
25	05		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This study was conducted to quantify, as a function of speech intelligibility, the performance achieved by 30 normal hearing tank crews when conducting gunnery scenarios in an armor simulator. A scenario consisted of 10 missions. Four targets (tank, truck, helicopter, or troops) appeared during each mission, and it was the commander's task to instruct the gunner to shoot at the appropriate target with the appropriate weapon. The speech intelligibility (SI) measure used was the modified rhyme test (MRT). Performance measures (for each scenario) were recorded at nominal SI levels of 100%, 75%, 50%, 25% and 0%.

The specific measures used to evaluate performance as a function of SI were categorized as follows:

(see reverse side)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Technical Reports Office	22b. TELEPHONE (Include Area Code): (301) 278-4478; 22c. OFFICE SYMBOL: SLCHE-SS-TSB

19. (continued)

1. Mission time /--/

   a. Time to identify the target,
   b. Time to fire upon the target,
   c. Time to kill the target, and
   d. Time to accomplish the mission;

2. Mission completion /--/

   a. Percent of targets identified and
   b. Percent of targets killed;

3. Mission errors /--/

   a. Percent of crew killed,
   b. Percent of times wrong target was killed, and
   c. Percent of communication errors;

4. Gunner accuracy /--/

   a. Number of rounds required to kill a target
   b. Aiming error

This report provides results from these performance measures and quantifies the changes in armor gunnery performance as a function speech intelligibility.

Keywords: Voice communications, Intercommunication systems, (CBR)

AMCMS Code 611102.74A0011

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THE EFFECTS OF SPEECH INTELLIGIBILITY ON CREW PERFORMANCE IN AN M1A1 TANK SIMULATOR

INTRODUCTION

The ability of personnel to communicate accurately can be paramount to the successful operation of soldier-machine systems. Degradation of speech intelligibility may lead to misunderstandings, operational errors, and the increased risk of accidents. More specifically, communication in tracked vehicles is essential to system performance.

Understanding commands or instructions can often mean the difference between life and death. Unfortunately, it is often difficult to transmit commands or orders because of noise, hearing loss, or distractions associated with tank operations.

Case histories can be cited in which a tank commander was unable to direct the driver to take certain action, or the gunner misunderstood a command and fired at the wrong target, or because of communication difficulty, a fire command took too long to be understood and the enemy target was no longer in sight, or worse still, the enemy was able to fire the first shot.

The recent history of armored vehicles includes a number of ingenious adaptations to overcome communication difficulties. Some of these are pulling a rope tied to the driver to tell him to stop, poking the gunner on the shoulder to indicate turret direction, providing a light box to tell the driver to turn right or left. These illustrations indicate that communication in current vehicles is difficult enough that crews realize some corrective action is necessary for them to perform their mission. Ideally, proper communication systems should be designed into the vehicle and should not depend on the innovativeness of the crew.

Currently, design guidance is given in MIL-STD-1472D (1989), which recommends levels of speech intelligibility for various communication situations. This standard requires a modified rhyme test (MRT) score of 97% for "exceptionally high intelligibility," 91% for "normally acceptable intelligibility," and 75% for "minimally acceptable intelligibility." These requirements were based on subjective judgments by experts in the field, rather than on studies of the ability of personnel to perform under various levels of speech intelligibility. The levels required by MIL-STD-1472D should be validated with data that relate total system performance to the level of speech intelligibility available to the crew. Therefore, the present study is intended to begin the process of providing an empirical base for the standard by quantifying performance as a function of speech intelligibility.

Data about performance as a function of speech intelligibility would also be useful to operations analysts who are called upon to assess the effects of different variables on the outcome of a battle. Given a performance data base, computer programs simulating battle under different conditions could be improved by including speech intelligibility as a variable.

The present study is part of a larger program studying the use the human being makes of auditory information and the effects various auditory handicaps have on the ability of soldiers to perform military tasks. Such handicaps might be the result of poor system design as well as the result of factors such as hearing loss, masking noise, the wearing of earplugs under a headset, and so forth.

The goal of the present study was to begin establishing a theoretical base upon which to construct a model. Based on the literature, it was decided that a model of performance (which depends on communication) must take four factors into consideration:

1. The level of speech intelligibility. The hypothesis is that as speech intelligibility is decreased, performance is also decreased.

2. The structure of communication. All communication can be explained as

a. One way--a single talker dictates to the listener(s), and there is no verbal feedback (e.g., a commander gives his gunner a fire command).

b. Two way--a single talker questions the listener(s), and the listener(s) provide the requested information (e.g., a commander asks several platoon leaders for their morning report).

c. Three way--several participants are involved in a discussion. The outcome of this discussion will form the basis for a response or decision (e.g., several commanders coordinate an attack plan).

The hypothesis associated with this factor concerns whether a performance curve will differ as a function of communication structure within a level of intelligibility.

3. The message set. This factor is viewed as being comprised of two variables, criticality and efficiency. Criticality is the degree to which the target performance requires communication and message efficiency, which can be described as a method of rating one message from another as a function of performance.

4. Personal ability. This factor is believed to be primarily composed of resources that the talker or listener brings to the task and training, which the talker or listener has acquired to do a specific task.

PURPOSE

The purpose of this study was to test the hypothesis that performance would vary as a function of speech intelligibility (Factor 1) and to establish initial performance curves for one-way communication (Factor 2).

Tank crews conducting gunnery exercises in a tank simulator under different levels of speech intelligibility were chosen to provide the

performance measures. Gunnery using a tank simulator represents a comparatively simple, well-defined military task with relatively easily quantified outputs.

The measures of performance included (a) time required to perform a mission, (b) degree of mission completion, (c) mission error rate, and (d) gunner accuracy.

A subjective work load analysis was also included to evaluate the task difficulty imposed by changes in speech intelligibility.

METHOD AND PROCEDURE

Subjects

Sixty subjects were combined to form 30 two-man crews (commander and gunner). These crews had an average of 7 years' experience as tankers, were assigned to the Armor School, Fort Knox, Kentucky, and had prior training on the conduct of fire trainer (COFT). All subjects were screened in the Audiology Department of the Fort Knox Hospital 2 weeks before the experiment to establish that they all had hearing that met the requirements for an H1 profile (hearing thresholds less than 25 dB[A] from 250 Hz through 2,000 Hz and not exceeding 35 dB[A] at 4,000 and 6,000 Hz bilaterally). Further, they were able to communicate, using the MRT, which requires the ability to speak clearly as well as to hear at an initial level of at least 80%. Before the experiment, the crews were trained until they consistently achieved a speech intelligibility score, under ideal conditions, of at least 96% when using the MRT.

Tank Simulator

The study was performed in the COFT simulation facility at Fort Knox. This simulator is a training system for the commander and gunner that realistically simulates the functions, controls, sights, panels, and so forth of an operational M1A1 tank. Visual scenes are presented as graphic displays through the normal vision blocks and telescopes by means of computer-controlled monitors. The computer simulates an area 3 kilometers deep and 6 kilometers wide. The COFT simulator can present a variety of scenarios from a stationary friendly tank with stationary enemy targets to a moving friendly tank with multiple moving enemy targets.

During the scenarios, the COFT system computed a number of scores that were used to determine the crews' performance: target identification time, time to fire the first round, time to kill the target, friendly vehicle exposure errors, aiming errors, switch setting errors, target classification and system management errors, ammunition selection and lasing errors.

For this study, the COFT "orientation" scenario was selected as the basis for the exercises conducted in this experiment. In this scenario, four stationary targets appear at the same time on a European landscape. These

targets consist of a tank appearing from behind a hill, troops appearing in front of a large rock, a truck appearing from behind a barn, and a helicopter appearing from a hill crest.

Scenario

The scenarios consisted of a closed set of commands that were read to the gunner by the commander (see Appendix A). These were normal commands that would be used in gunnery tactics (i.e., GUNNER - SABOT - TANK, which alerts the GUNNER that he is to locate the enemy TANK and shoot a SABOT round at it).

Since all four targets appeared at the same time, the gunner was given standing instructions that he was to shoot only at the target specified by the commander. (He was told that the commander had information unavailable to the gunner that certain targets were friendly or that the targets were to be shot in a certain sequence.) Also, to make the task somewhat more communicatively intense, the scenario was conducted under the assumption that the commander's operating control was inoperative and that he had to "talk the gunner onto the target" and was not able to shoot (see commander and gunner instructions in Appendix B).

Each scenario consisted of 10 encounters in which one to three targets were required to be engaged. Before engaging any of the targets within an encounter, the commander directed the gunner to set a certain condition within the fire control system. The conditions used were

Close ballistic door, use gunner's auxiliary sight (GAS).

When the gunner closed the ballistic doors and used the GAS, he was unable to see forward of the berm and had to rely solely on the commander's verbal directions to acquire the target.

Lay on barn, check drift.

Here, the gunner was required to lay his sight on the corner of the large barn to his front and check for drift of his sighting mechanism.

Go thermal imaging sight (TIS).

Here, the gunner was required to view through his TIS.

Go to manual mode, use GAS.

In this mode, the gunner was required to turn the turret using the manual controls and to use the GAS, which prevented his seeing forward of the berm and required verbal directions from the commander to acquire the target.

Frequent changes were made during the encounters in which the commands "cease fire" or "correction, change target" were transmitted to the gunner by the commander. These commands were included to add communication intensity to the encounter.

Before the experiment, the commander was instructed to speak each line of the script and not to proceed to the next line unless he received a verbal or action response from the gunner. If the commander did not receive a response, he was to repeat the last command or use his own words. Commands not transmitted to the gunner or acted upon incorrectly by the gunner were considered to be communication errors.

Speech Intelligibility Test

The MRT was used to measure the speech intelligibility (House, Williams, Hecker, & Kryter, 1963). The MRT consists of six lists of 50 monosyllabic English words. To establish the level of intelligibility, one of the lists was read by the commander to the gunner, and then another list was read by the gunner to the commander. The constant phrase, "would you mark ___ now" was used to enclose the target word. The listener then selected the spoken target word from among a closed set of six rhyming words. The intelligibility score was the percent of words correctly chosen, adjusted for chance:

$$R_A = R - W/5$$

in which R_A is the adjusted number of correct words

R is the number of words correctly received

W is the number of words incorrectly received

Instrumentation

Speech intelligibility was controlled by passing the speech signal through a chopping circuit (an electronic circuit that limits the amount of time an ear has to respond to a speech signal) and by adding speech-shaped masking noise. The masking noise was set at a level of 85 dBA when measured by an artificial ear at the earphones of the tanker's helmet. Masking was necessary to prevent shouted speech by the test subjects from being heard directly, bypassing the chopping circuit. The chopping circuit was set at a rate of 60 Hz per second, with the duty cycle being variable from 0 to 100%. The duty cycle for each nominal level of intelligibility was set by a 10-turn potentiometer as follows (the numbers in parentheses indicate the acceptable range of intelligibility for each nominal value):

Intelligibility (%)	Duty cycle (%)
100 (100 to 90)	97.6
75 (89 to 65)	53.6
50 (64 to 35)	35.2
25 (34 to 10)	14.5
0 (9 to 0)	1.7

Subjective Work Load Assessment Technique

The Subjective Work Load Assessment Technique (SWAT) is a method in which subjects are asked to rate the subjective work load of their task (in this case, the scenarios and the intelligibility tests) with respect to time, effort, and psychological stress (see Appendix C). The technique consists of rating each of these three factors as a 1 (easy), 2 (moderate) or 3 (difficult). Before the experiment, each subject was "calibrated" by rank ordering 27 cards that contain a description of a task having a specified level of time, effort and psychological stress. The ordinal ranking of these cards was used as a base line for evaluating the SWAT scores obtained during the actual experimental procedure.

Test Procedure

The study was conducted in the COFT M1A1 tank simulator in which a commander and a gunner were present. The driver and loader were simulated by the instructor-operator. The study consisted of each crew conducting gunnery scenarios (consisting of 21 targets) at nominal speech intelligibility levels of 100%, 75%, 50%, 25% and 0%.

Immediately before each test scenario, the commander and gunner read a single MRT list (50 words) to each other. Intelligibility had been set to the desired nominal level by means of an electronic chopping circuit. If the MRT score fell within a preselected range of the nominal value, the scenario was conducted. If the MRT score did not fall within the preselected range, the chopping circuit was readjusted and the intelligibility test repeated. After the proper MRT score was obtained, the gunnery scenario was conducted. Afterward, the intelligibility test was repeated, with the reported MRT score being the average of the two tests.

Immediately following each scenario, SWAT was administered to the commander and gunner to provide an estimate of the subjective work load imposed on each of them by the scenario. Also following each intelligibility test, the crew was asked to provide a SWAT rating of the intelligibility test as both talkers and listeners.

Following a rest period of approximately 1 hour, each of the other four intelligibility levels was presented in counterbalanced order using the same procedure. Two days' testing were required for each pair of crews.

RESULTS

Speech Intelligibility Scores

The average actual intelligibility obtained during the scenarios, as a function of the desired nominal communication settings, is shown in Figure 1. An average score of 100% was not achievable with the electronic chopping circuit set at its highest duty cycle mainly because of the quality of the communication system. The lowest average score selected was 7.1%, since the

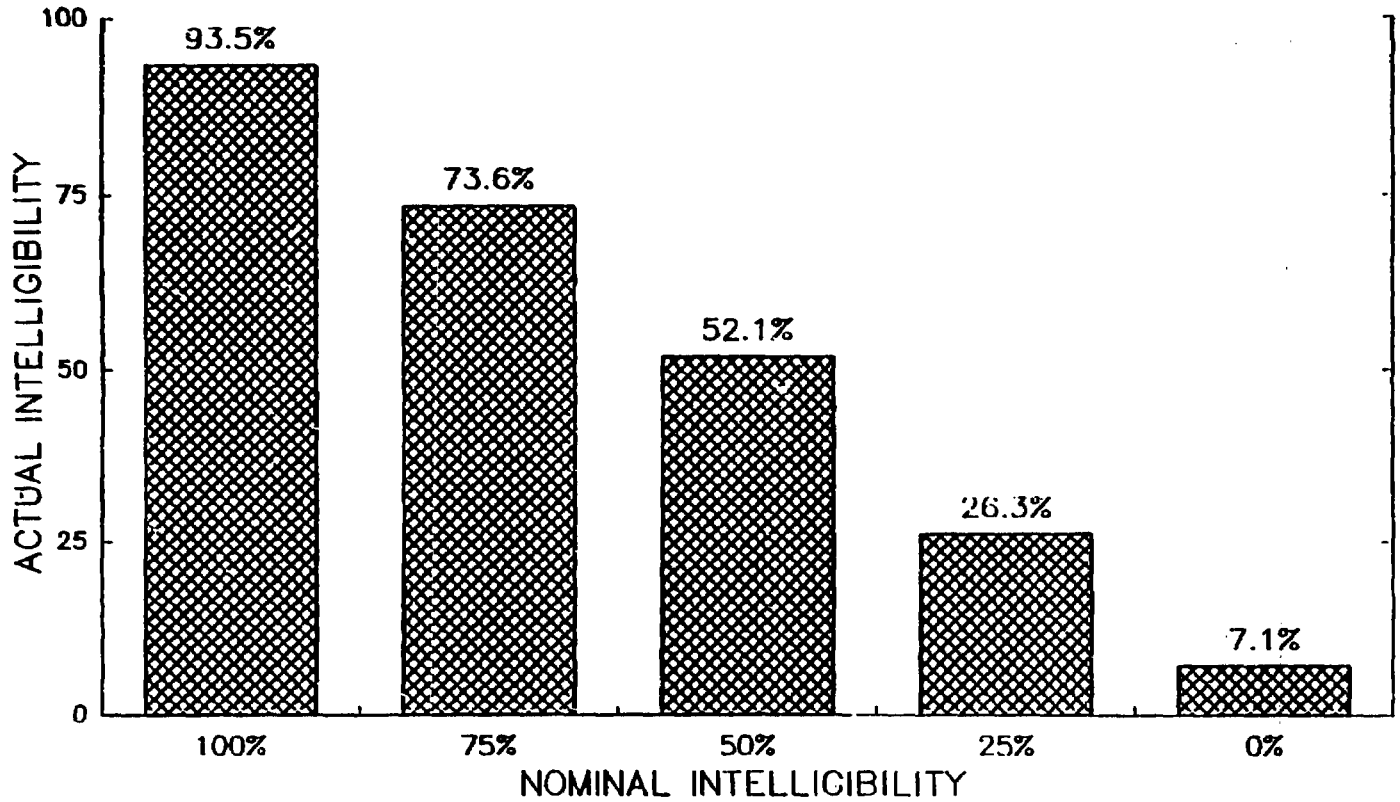

Figure 1. Actual speech intelligibility obtained versus nominal speech intelligibility setting.

authors wanted the crew to obtain some degree of information from their communications. It should be noted that these percentage scores are for performance on the MRT. Even with an MRT score of 0%, it was still possible for crews to use the communication system, sometimes ingeniously, to transmit information.

Subjective Work Load Assessment

The specific subjective work load question was "How did the crew's assessment of work load with respect to time, effort, and stress vary as a function of speech intelligibility?" Only the initial analysis of subjective work load is presented in this report. A second report devoted to work load measures is being prepared. Figure 2 displays the results of the average ranking provided by the subjects in the areas of time, effort, and stress. These data show a continuous increase in perceived difficulty for effort and stress, indicating that the subjects responded to the variation in communicative difficulty. While the time sub-task rating was not a smooth function of intelligibility, it showed an increase in perceived difficulty as a function of a decrease in intelligibility.

Performance

The four specific performance questions were (a) how did the time required to perform the missions change as a function of speech intelligibility; (b) how did the percent of mission completion vary as a function of speech intelligibility; (c) how did the number of mission errors change as a function of speech intelligibility; and (d) how did gunner accuracy vary as a function of speech intelligibility?

General Statistics

The performance data were parametric and were analyzed using both descriptive and inferential statistics. This analysis of time to identify, time to hit, time to kill, and distance of hit from center of mass was performed using standard repeated measures techniques. Assumptions, such as compound symmetry and independence of the measures, were checked and transformed as needed. A multiple comparison test, which used Tukey's wholly significant difference, was used to control the family-wise error and to produce all required contrasts.

There was one independent variable--speech intelligibility. The dependent variables were the various reaction times and percent accomplishment of various tasks.

The work load data (SWAT) were non-parametric and were analyzed using a log-linear model using chi-square statistics.

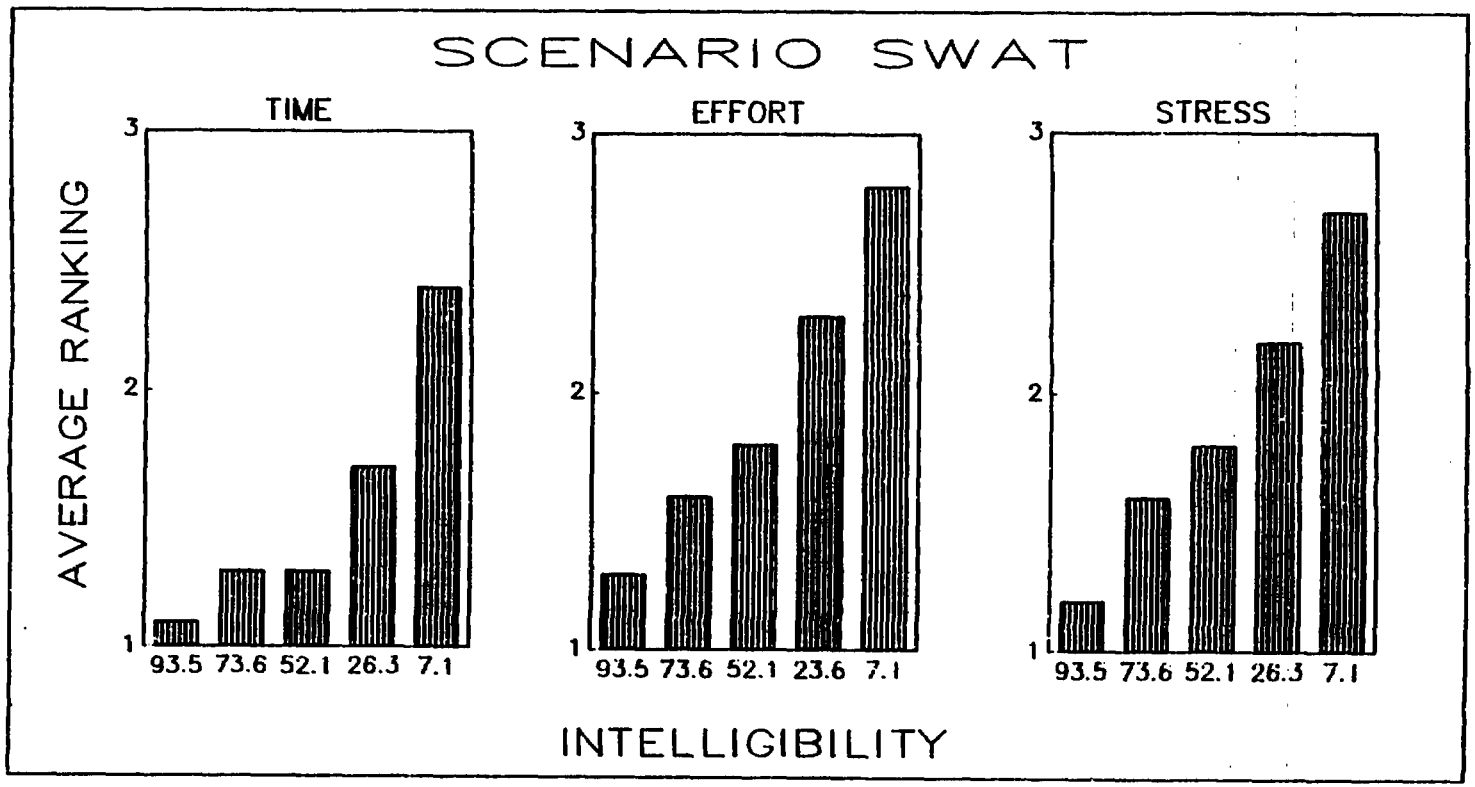

Figure 2. SWAT ranking obtained for the scenarios.

Descriptive Statistics

Three reaction times had been recorded: the time required to identify, fire at, and kill various targets for both single and multiple target missions. The overall mission time was also recorded. The purpose of the descriptive statistics was to obtain a measure of central tendency and to see what statistical treatment would be required for an in-depth analysis.

Figure 3 displays the times required to identify a single target. The graph indicates a fairly flat slope which becomes steeper at an intelligibility of about 25%. Table 1 displays a summary of the average time to complete various aspects of an encounter (identify, fire, kill) at each intelligibility level for the single target mission. The average time to identify ranged from 7.2 seconds at 100% intelligibility to 22.6 seconds at 0%. The average time to fire ranged from 14.3 to 29.8 seconds. The average time to kill ranged from 15.2 to 30.9 seconds. It should be noted that the above data reflect 30 crews completing five single target missions at each intelligibility level.

Figure 4 displays the relationship between identification, fire, and kill times for single target missions (individual crew results are listed in Appendix D).

Table 2 displays a summary of the average time to complete various aspects of an encounter (identify, fire, and kill) at each intelligibility level for the multiple target missions. The average time to identify ranged from 8.1 seconds at 100% intelligibility to 10.1 seconds at 0%. The average time to fire ranged from 7.5 seconds to 11.1 seconds, and the average time to kill ranged from 8.1 to 11.2 seconds.

Figure 5 depicts the relationship between identification, fire and kill times for multiple target missions (individual crew results are listed in Appendix D).

Figure 6 depicts the time required to complete a multiple target mission. This curve is very similar in shape to the identification time curve, having a fairly flat slope which becomes steeper at about 25% intelligibility.

Table 3 lists a descriptive statistic summary for the effect of speech intelligibility on the overall mission time (individual crew results are listed in Appendix D). The average mission time for the five levels of speech intelligibility ranged from 55 seconds at 0% to 39 seconds at 100% speech intelligibility.

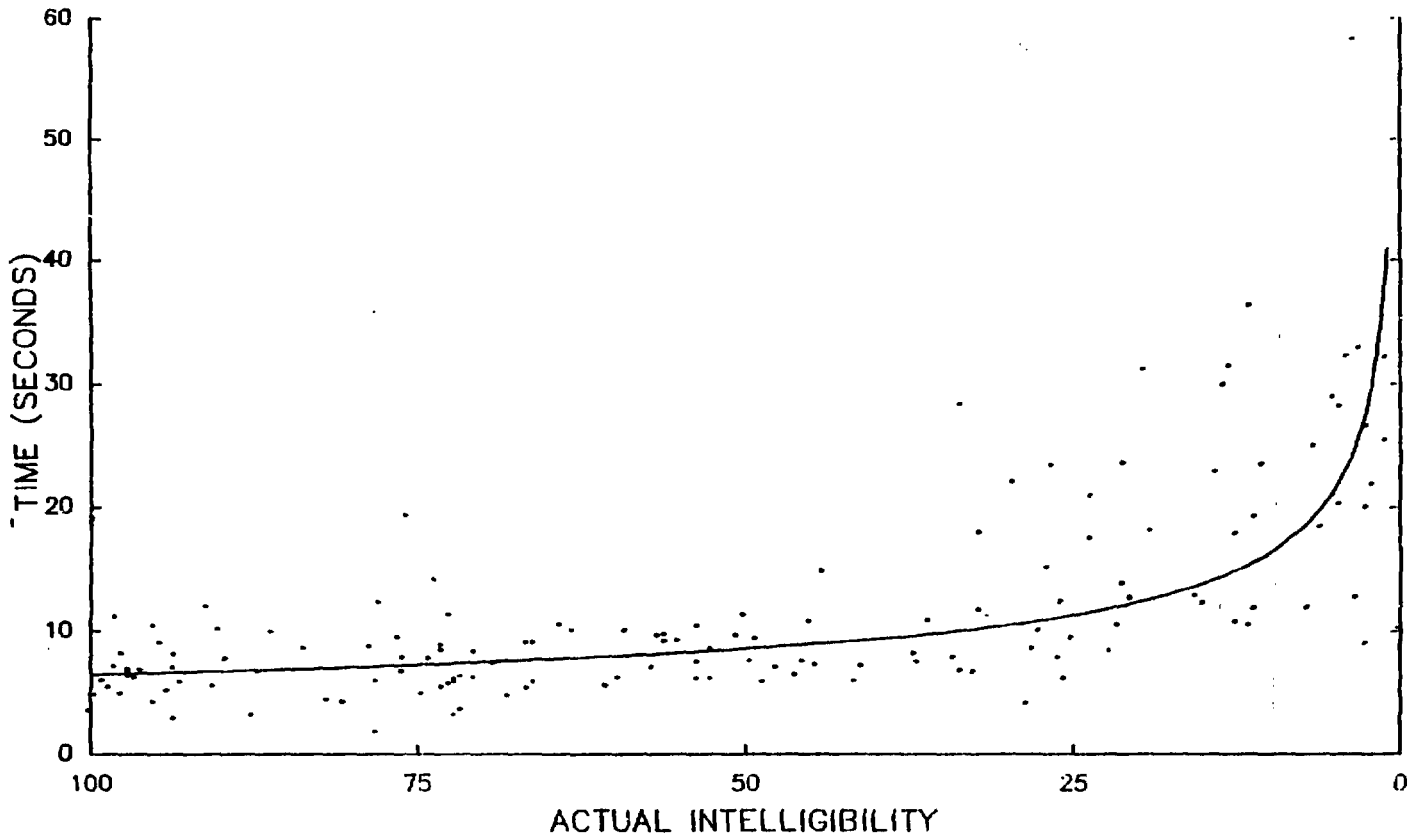

Figure 3. Time required to identify a single target.

Table 1

Descriptive Statistical Summary for the Effect of Speech Intelligibility on the Identification, Fire and Kill Times for Single Targets

IDENTIFICATION

Variable	Value label	Mean	SD[a]	Cases
Speech intelligibility level	0	22.5707	12.3523	150
Speech intelligibility level	25	12.1200	10.0135	150
Speech intelligibility level	50	8.5560	9.9537	150
Speech intelligibility level	75	7.5380	7.2935	150
Speech intelligibility level	100	7.1607	6.1834	150
For entire population		11.5891	11.0210	750

FIRE

Variable	Value label	Mean	SD	Cases
Speech intelligibility level	0	29.7873	13.4493	150
Speech intelligibility level	25	18.6007	8.6441	150
Speech intelligibility level	50	15.3853	6.3767	150
Speech intelligibility level	75	15.4413	8.0118	150
Speech intelligibility level	100	14.2600	5.4153	150
For entire population		18.6949	10.5088	750

KILL

Variable	Value label	Mean	SD	Cases
Speech intelligibility level	0	30.8947	13.3938	150
Speech intelligibility level	25	19.1427	8.5485	150
Speech intelligibility level	50	16.2867	6.4646	150
Speech intelligibility level	75	16.5080	8.3268	150
Speech intelligibility level	100	15.1507	5.8448	150
For entire population		19.5965	10.6205	750

[a]SD = Standard deviation

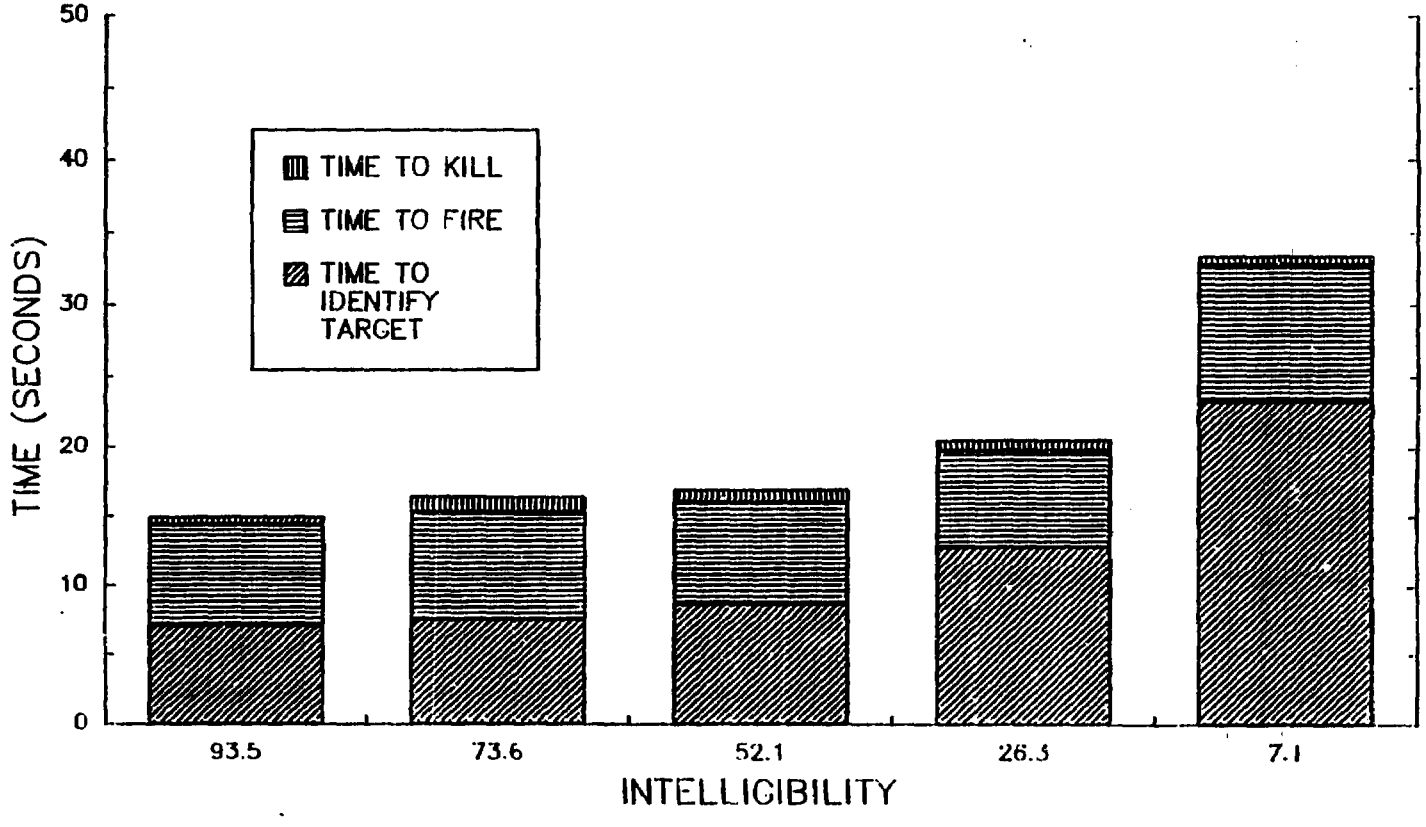

Figure 4. Time required to identify, fire upon, and kill a single target.

Table 2

Descriptive Statistical Summary for the Effect of Speech Intelligibility on the Identification, Fire and Kill Times for Multiple Targets

IDENTIFICATION

Percent speech intelligibility	Sum	Mean	SD	SS[a]	Cases
0	11204.3	24.8984	10.1433	46196.0089	450
25	7818.2	17.3738	11.4525	58890.2906	450
50	6222.3	13.8273	9.3810	39513.5738	450
75	5516.2	12.2582	8.6321	33456.4546	450
100	5458.7	12.1304	8.0720	29255.9129	450

FIRE

Percent speech intelligibility	Sum	Mean	SD	SS	Cases
0	14163.1	31.4736	11.0996	55317.5153	450
25	10373.5	23.0522	10.6997	51403.3028	450
50	9301.3	20.6696	8.8644	35281.3329	450
75	8722.1	19.3824	9.1950	37961.7313	450
100	8340.4	18.5342	7.4783	25110.6330	450

KILL

Percent speech intelligibility	Sum	Mean	SD	SS	Cases
0	14910.8	33.1351	11.1768	56089.6252	450
25	11061.3	24.5807	10.8416	52776.0618	450
50	10103.3	22.4518	10.2753	47406.5436	450
75	9436.2	20.9693	9.7435	42625.7768	450
100	8914.5	19.8100	8.1387	29741.1650	450

[a]SS = Sum of squares

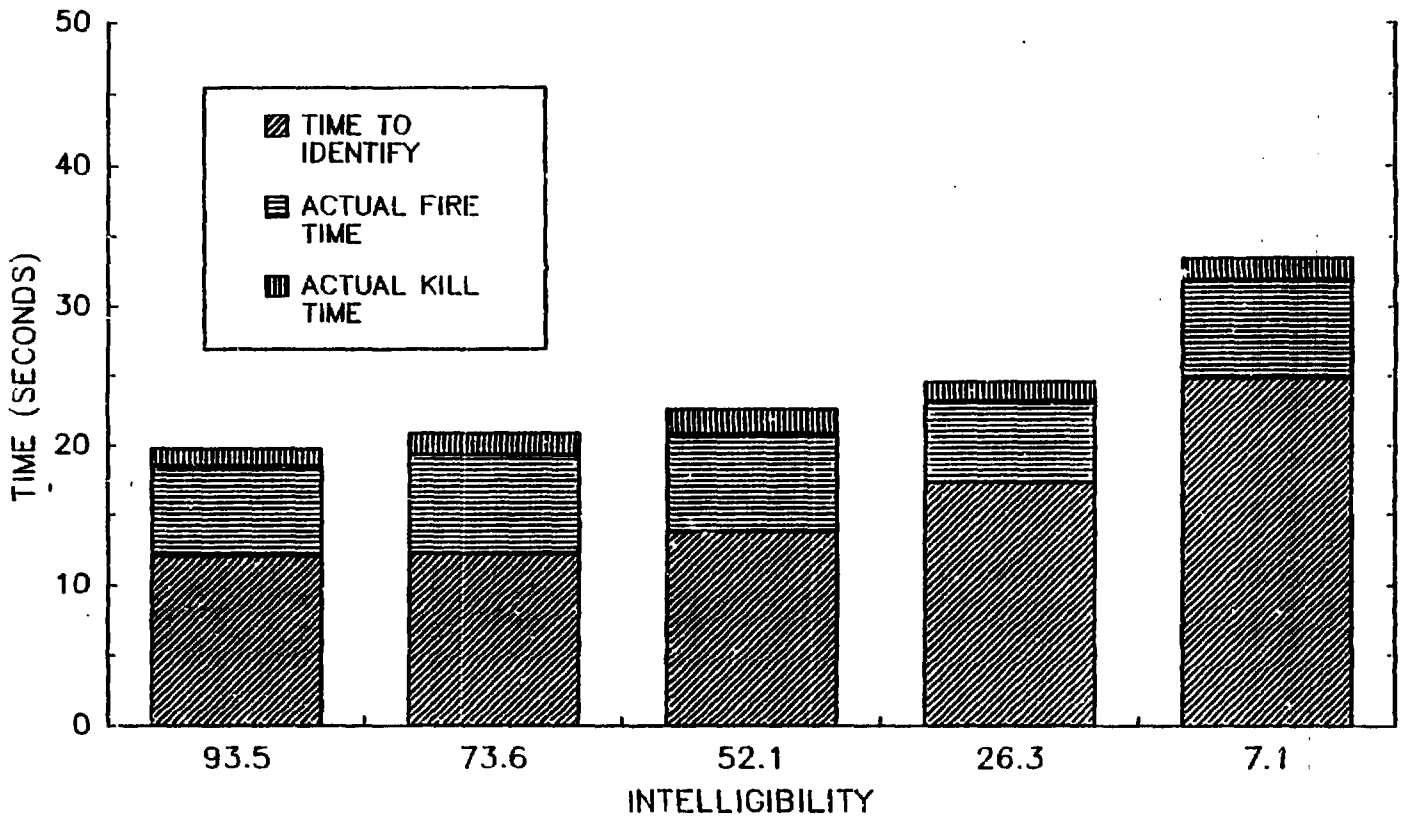

Figure 5. Time required to identify, fire upon, and kill each target in multiple target missions.

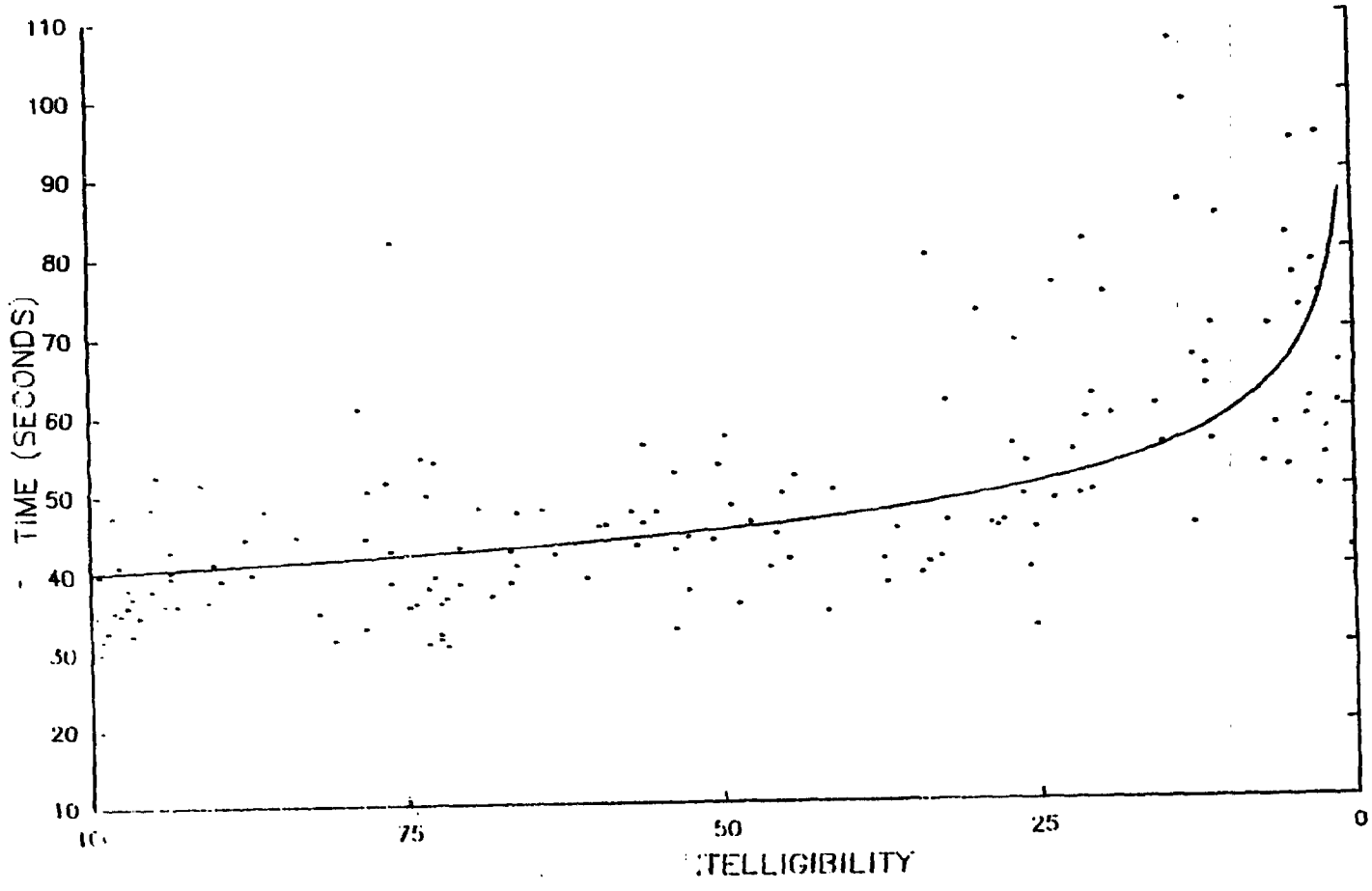

Figure 6. Time required to complete a mission.

Table 3

Descriptive Statistical Summary for the Effect of Speech Intelligibility on Overall Mission Time

Percent speech intelligibility	Mean	SD	Cases
0	55.6693	23.8840	300
25	48.0413	18.5210	300
50	44.7313	15.9958	300
75	41.5560	16.0158	300
100	39.5800	12.3047	300

The data about the effect of speech intelligibility on mission completion, number of mission errors, and gunner accuracy are given in Figures 7 through 13.

Data relating to the degree of mission completion as a function of intelligibility are summarized in two areas: percent of targets identified (see Figure 7) and percent of targets killed (see Figure 8).

Mission errors have been summarized in three areas: the percent of times the crew was killed, the percent of times the wrong target was shot, and the number of communication errors made.

Figure 9 presents the percent of friendly tank crews killed by enemy fire. These figures reflect the number of tank crews who were exposed to enemy fire for longer than 18 seconds and were considered to be casualties. (The Armor School provided the criterion of an 18-second exposure time.)

Figure 10 shows the percent of times the wrong target was shot. The wrong target was defined as any target killed by the gunner which was not so directed by the commander.

Figure 11 depicts the number of communication errors made as a function of speech intelligibility. For the purpose of this report, a communication error was considered to have been made each time a command was incorrectly acted upon by the gunner or not transmitted to the gunner by the tank commander.

The effect of speech intelligibility on gunner accuracy is shown in Figure 12, which displays aiming error as a function of intelligibility. The results indicate almost no change in reticle aim across different levels of speech intelligibility. Figure 13 indicates the number of rounds required to kill a target. As speech intelligibility decreased, the percent of times that

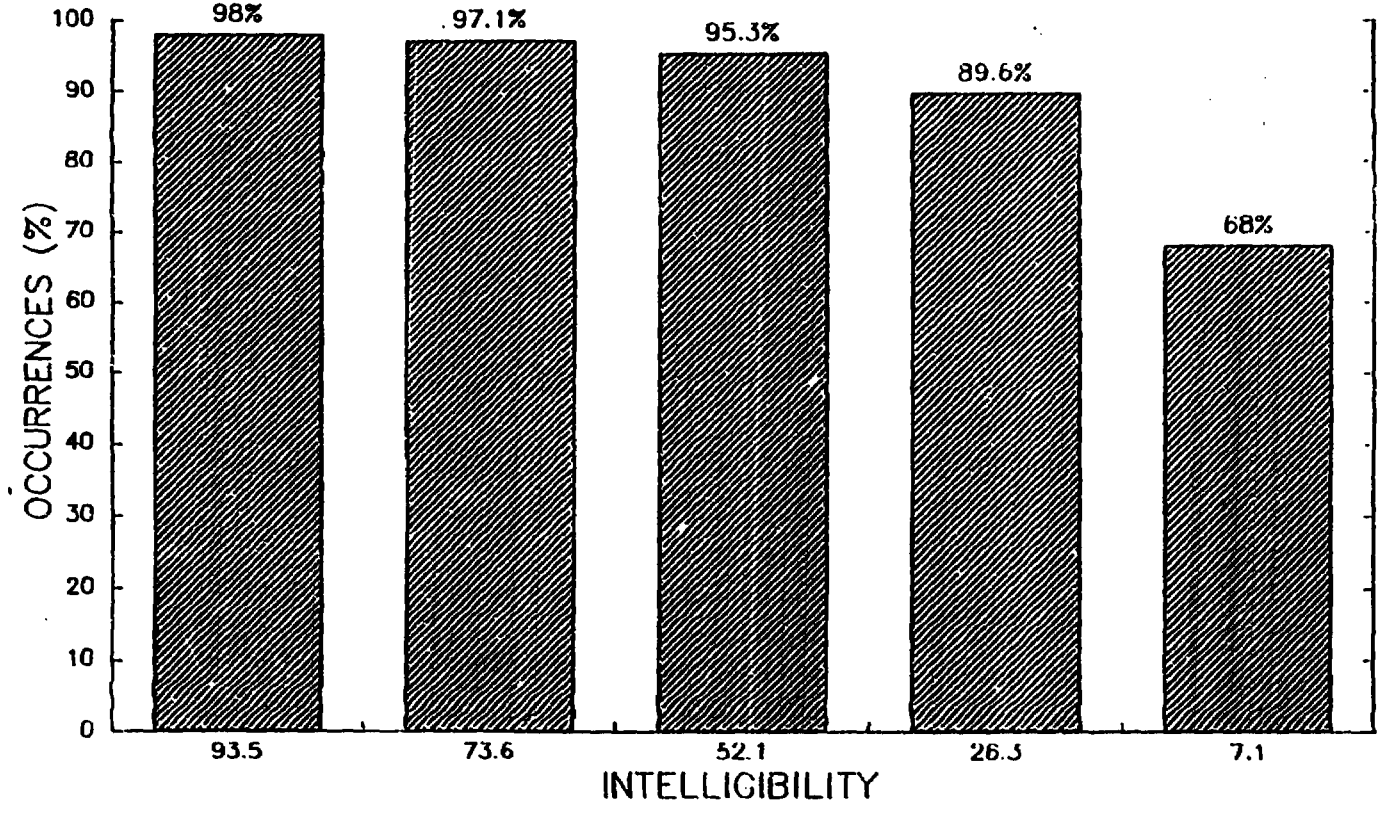

Figure 7. Percent of targets identified.

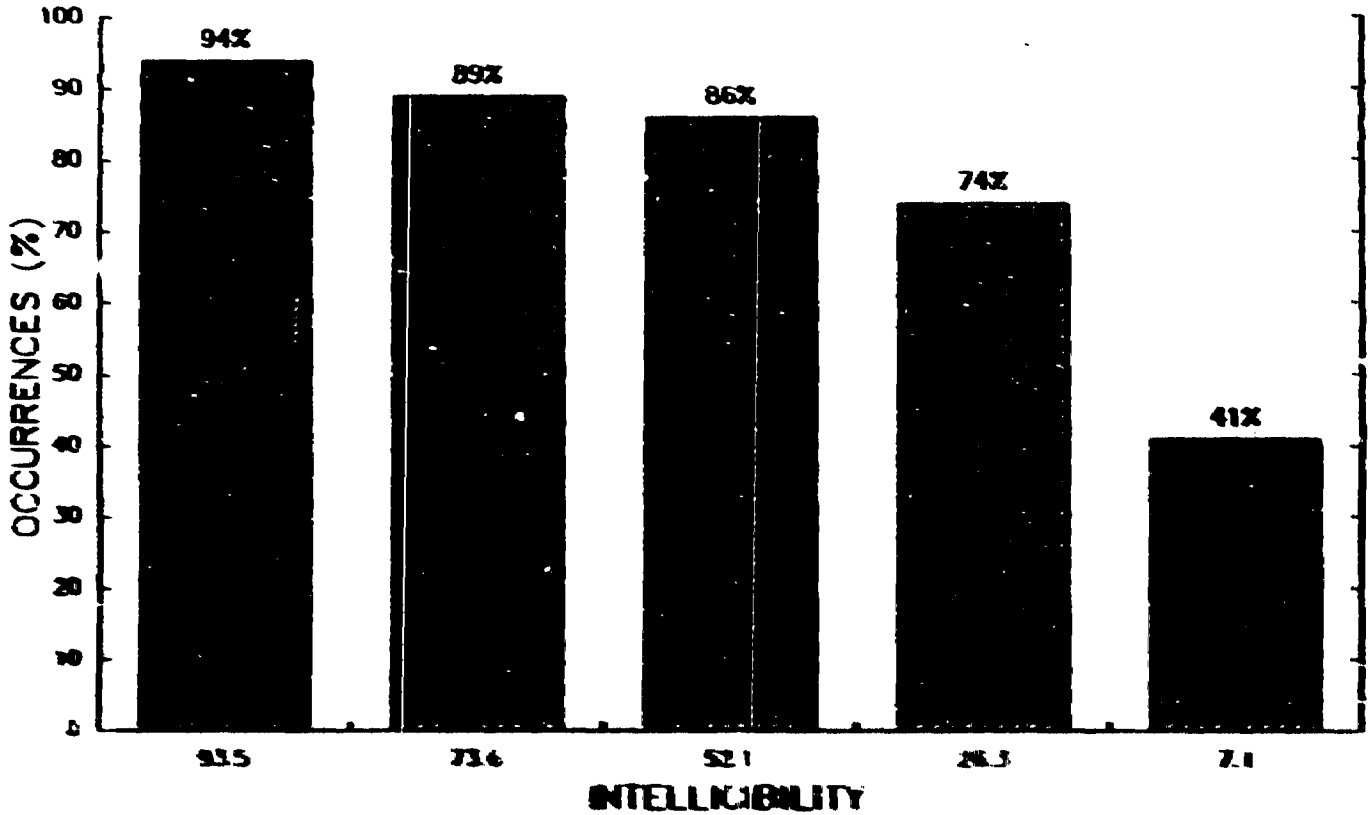

Figure 8. Percent of targets killed.

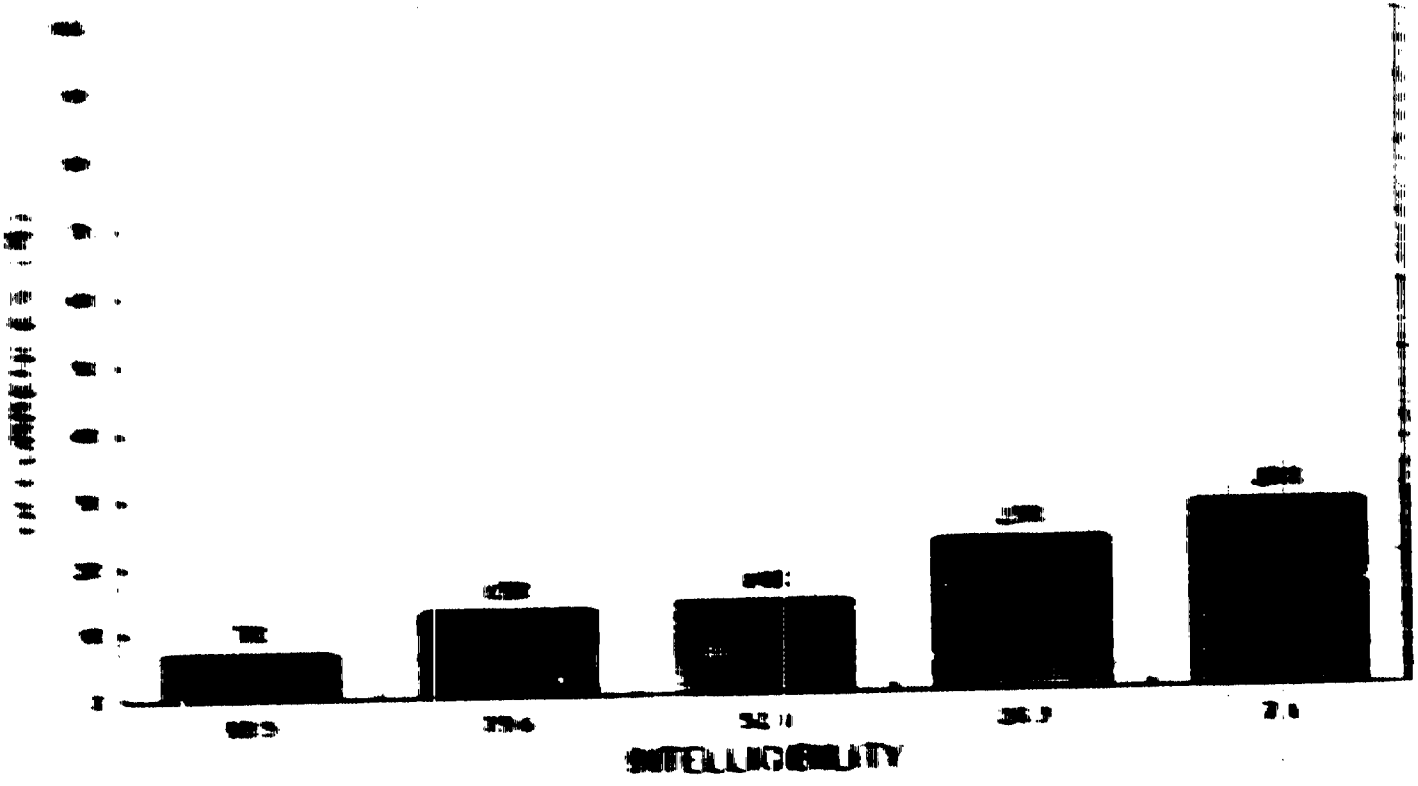

Figure 9. [illegible] tank crews killed by enemy fire.

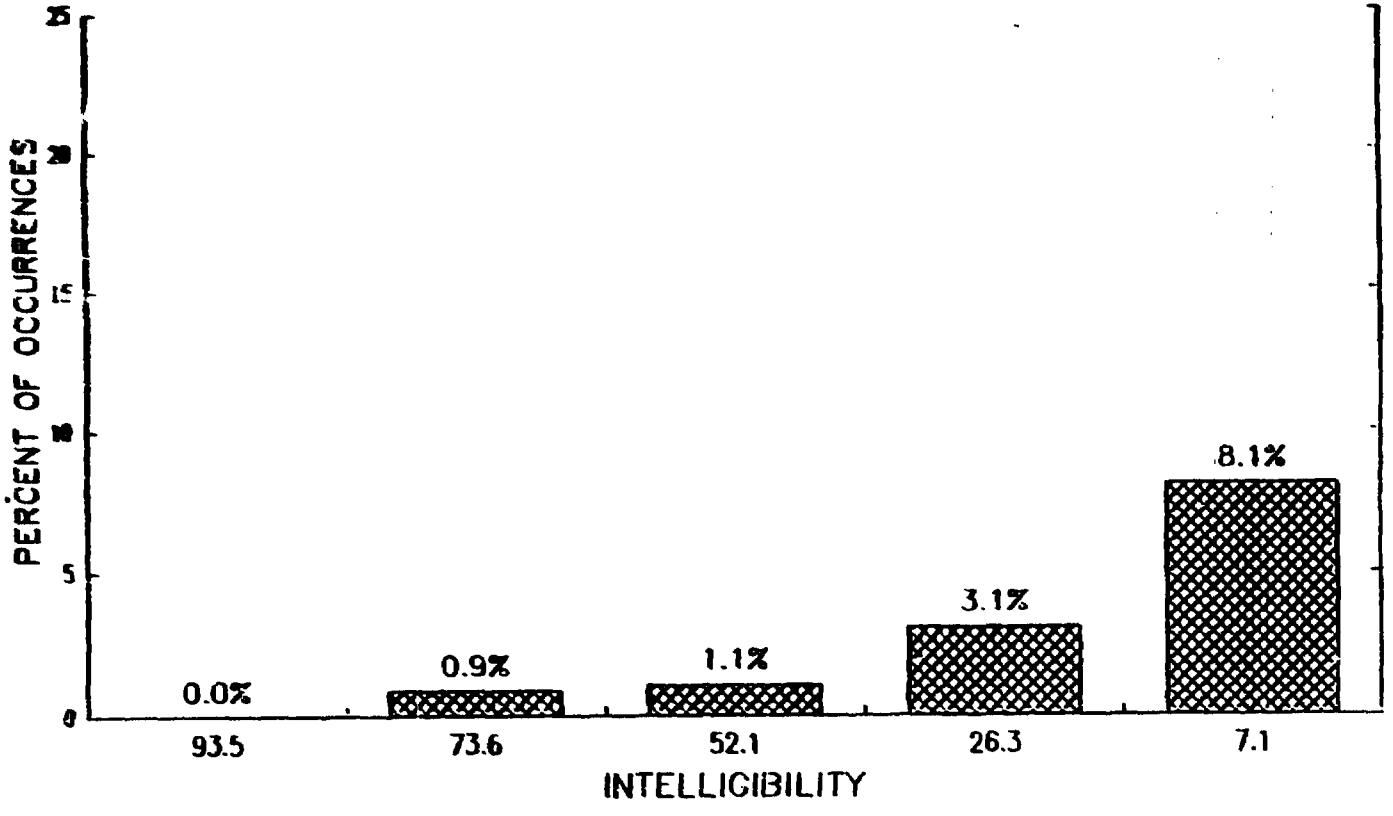

Figure 10. Percent of times wrong target was shot.

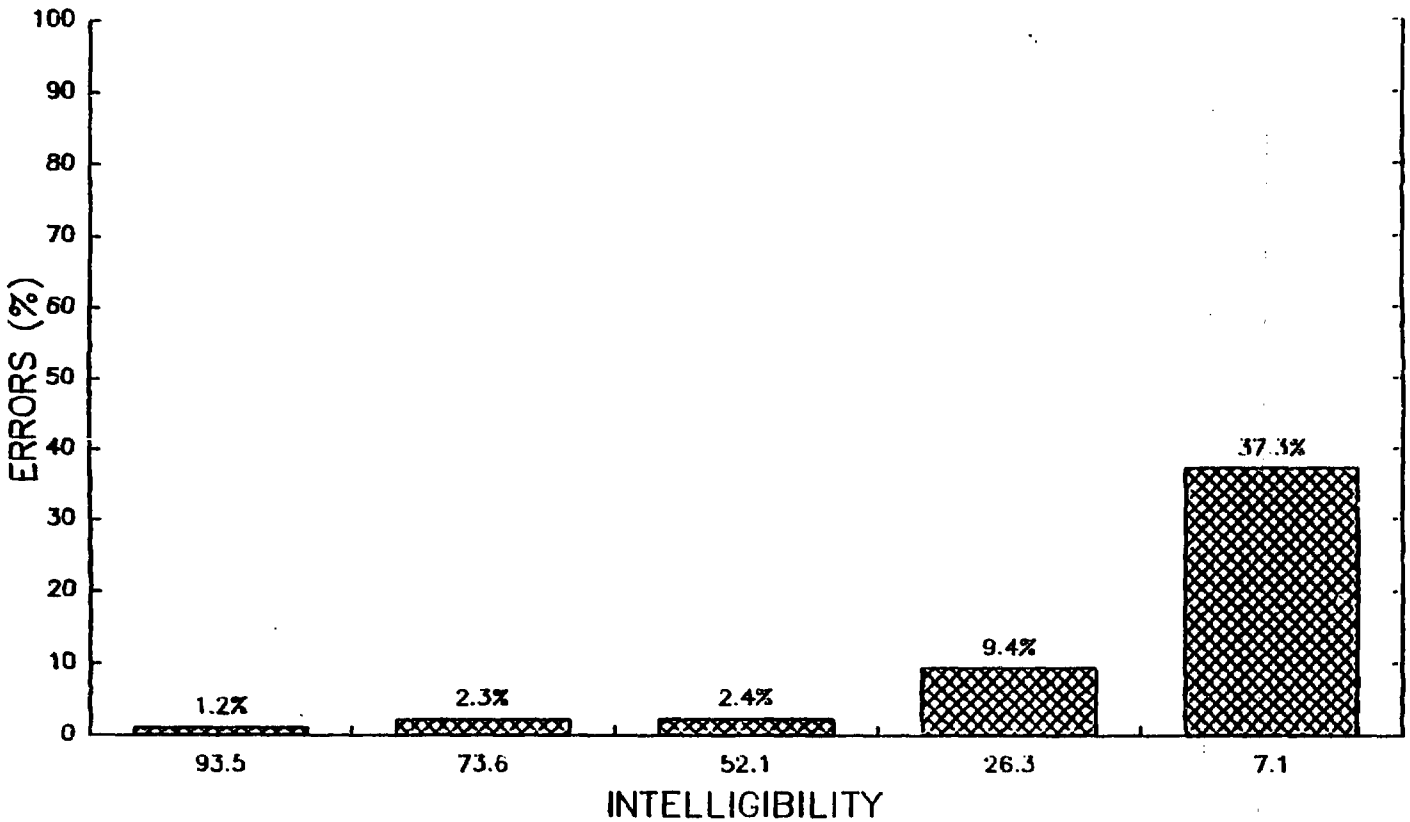

Figure 11. Percent communication errors.

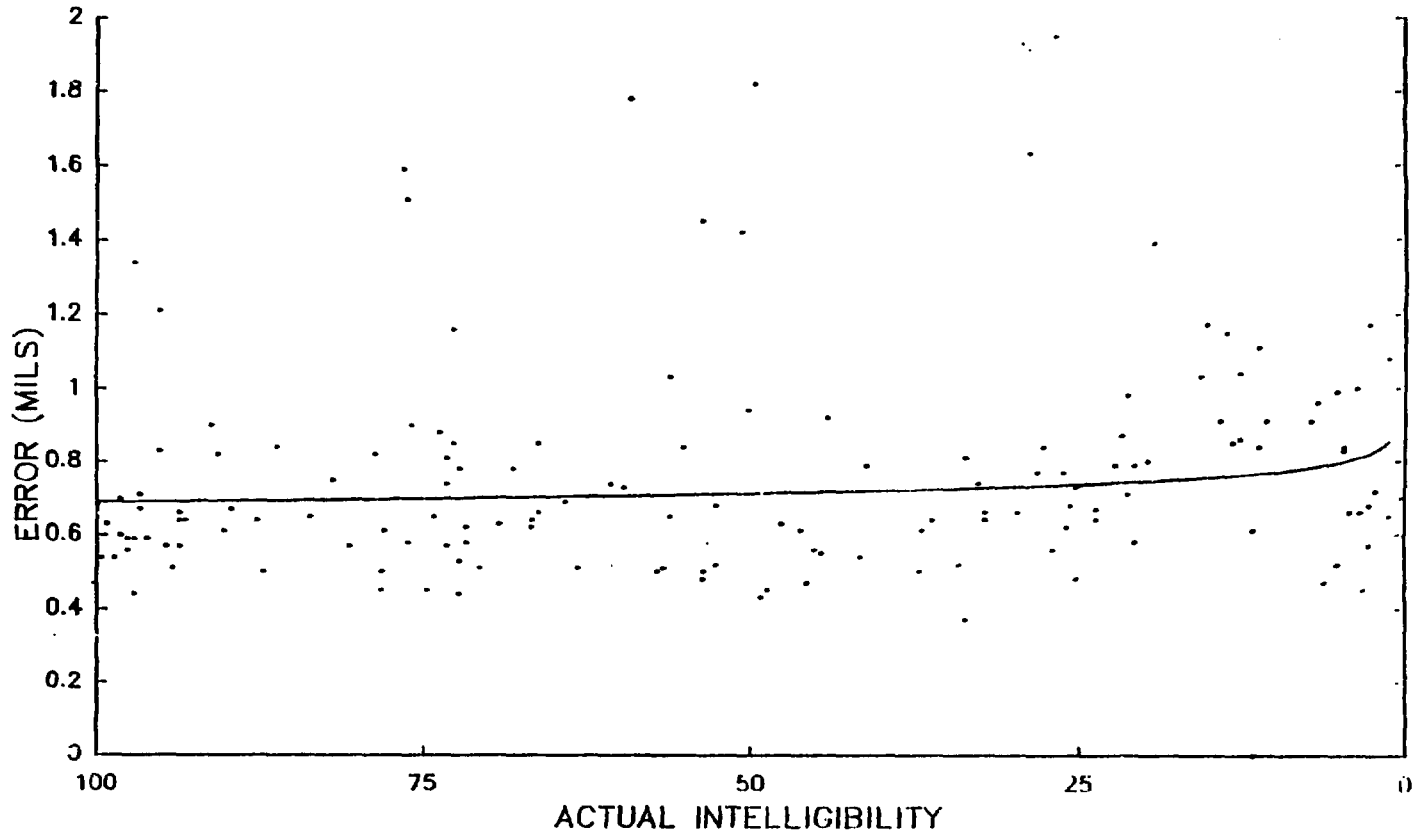

Figure 12. Aiming error.

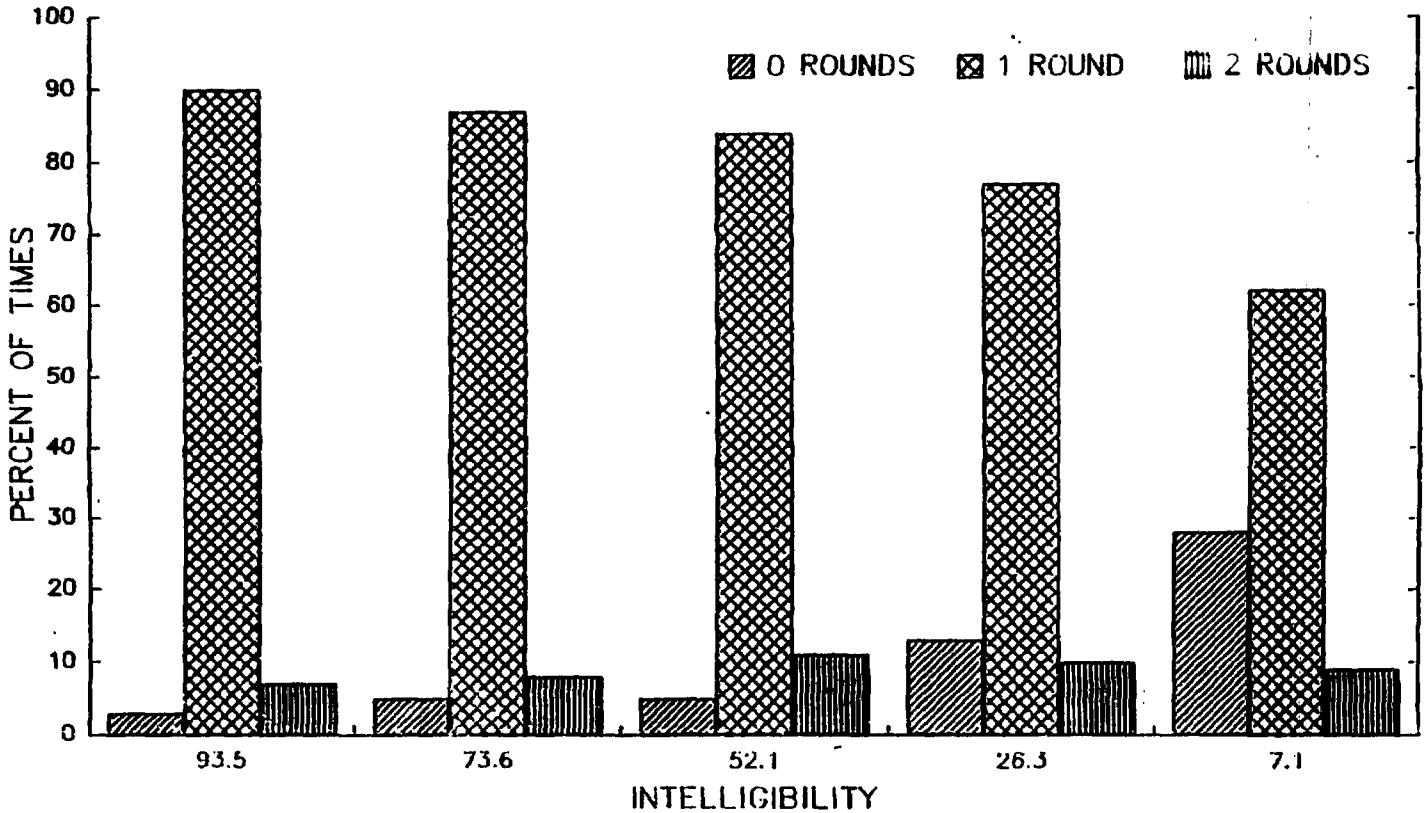

Figure 13. Percent of times no, one, or two rounds were fired at a target.

no rounds were fired increased from 3% to 27%, and conversely, the percent of time that the crew was able to kill the target with one round fell from 90% to about 62%.

Inferential Statistics

Before the actual analysis, Hotellings' test of significance was performed on all descriptive data sets. In all cases, Hotellings' F was significant. This indicates that correlations and variances were not equal among the different levels of each data set. Therefore, a multiple analysis of variance (MANOVA) was required. A univariate analysis of variance (ANOVA) was completed when a significant MANOVA was found.

The first performance objective (to see if mission time varied as a function of speech intelligibility) used specified reaction time data from single or multiple targets: identification, fire, and kill times. The overall mission time was also analyzed using a MANOVA. The purpose in conducting an in-depth analysis was two-fold: to see if a significant reaction time difference occurred among the various levels of speech intelligibility, and to see where that significance occurred. Although it is recognized that significance may not be of practical concern for evaluating the importance of communications during gunnery scenarios, it reveals the reliability and repeatability of the experimental results.

Tables 4, 5, and 6 list the MANOVA summaries for the effect of speech intelligibility on the time required to identify, fire upon, and kill a single target, respectively. A significant F was obtained and contrasts were run between levels of speech intelligibility. The contrasts for 100% versus 75% and 75% versus 50% intelligibility were not significant for any of the three tables. The contrasts of 50% versus 25% and 25% versus 0% intelligibility were significant for identification, fire, and kill times, however. Tables 7, 8, and 9 list the MANOVA summaries for multiple targets. For identification time, similar contrasts from 75% to 0% were significant. For fire and kill times, only the contrasts from 50% to 0% were significant.

Table 10, which lists the MANOVA summary for overall mission time, shows that only the contrast of 25% versus 0% was significant.

The number of times a friendly crew was killed by enemy fire was the one result from the second mission objective which was evaluated using a MANOVA. Table 11 lists the MANOVA summary for this topic. The contrast for 100% versus 75% was significant. Seventy-five percent versus 50% was not determined to be significant, but 50% varied significantly from 25%, although a significant F was not found for the contrast of 25% to 0% intelligibility.

The number of communication errors committed as a function of speech intelligibility is a part of the third objective. The MANOVA results are listed in Table 12. The contrasts for 100% versus 75% and 75% versus 50% were not determined to be significant; however, the contrasts for 50% versus 25% and 25% versus 0% were determined to have a significant F statistic.

Table 4

MANOVA Summary for the Effect of Speech Intelligibility on the Time Required to Identify a Single Target

Bartlett Test of Sphericity: 31.78521 with 6 DF[a]

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.85688	38.91747	4.00	26.00	0.000
Hotellings	5.98730	38.91747	4.00	26.00	0.000
Wilks	0.14312	38.91747	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[b]	Hypothetical MS[c]	Error MS	F	Significance of F
SL100-75	4.27141	6.23122	0.68549	0.414
SL100-50	58.40865	19.22868	3.03758	0.092
SL100-25	737.84961	37.38619	19.73589	0.000
SL75-50	31.08972	28.24462	1.10073	0.303
SL50-25	381.06288	48.76296	7.81460	0.009
SL25-0	3276.49301	65.77591	49.81296	0.000

[a]DF = Degrees of freedom
[b]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.
[c]MS = Mean square

Table 5

MANOVA Summary for the Effect of Five Levels of Speech Intelligibility on the Time Required to Fire at a Single Target

Bartlett Test of Sphericity: 43.92453 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.85680	38.89075	4.00	26.00	0.000
Hotellings	5.98319	38.89075	4.00	26.00	0.000
Wilks	0.14320	38.89075	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	41.86645	14.86645	2.82399	0.104
SL100-50	37.99125	10.71752	3.54478	0.070
SL100-25	565.24161	29.73370	19.01014	0.000
SL75-50	0.09408	32.99292	0.00285	0.958
SL50-25	310.15105	25.46065	12.18158	0.002
SL25-0	3754.24533	65.59943	57.22985	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 6

MANOVA Summary for the Effect of Five Levels of Speech Intelligibility on the Time Required to Kill a Single Target

Bartlett Test of Sphericity: 38.41929 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.84373	35.09494	4.00	26.00	0.000
Hotellings	5.39922	35.09494	4.00	26.00	0.000
Wilks	0.15627	35.09494	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	55.27061	17.45194	3.16702	0.086
SL100-50	38.71488	12.29957	3.14766	0.087
SL100-25	478.08192	27.12804	17.62316	0.000
SL75-50	1.46965	36.43296	0.04034	0.842
SL50-25	244.70208	22.01212	11.11670	0.002
SL25-0	4143.28512	61.97500	66.85414	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 7

MANOVA Summary for the Effect of Speech Intelligibility on the Time Required to Identify Multiple Targets

Bartlett Test of Sphericity: 31.56585 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.92822	84.05477	4.00	26.00	0.000
Hotellings	12.93150	84.05477	4.00	26.00	0.000
Wilks	0.07178	84.05477	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	110.20833	1080.76902	0.10197	0.752
SL100-50	86.38296	13.11658	6.58578	0.016
SL75-50	16619.24033	3860.47620	4.30497	0.047
SL50-25	84896.56033	4448.37275	19.08486	0.000
SL25-0	382189.10700	4625.98631	82.61786	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 8

MANOVA Summary for the Effect of Speech Intelligibility on the Time Required to Fire at Multiple Targets

Bartlett Test of Sphericity: 41.99913 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.91560	70.51174	4.00	26.00	0.000
Hotellings	10.84796	70.51174	4.00	26.00	0.000
Wilks	0.08440	70.51174	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	4856.49633	1863.31564	2.60637	0.117
SL100-50	136.78945	11.69690	11.69450	0.002
SL75-50	11182.42133	5256.92133	2.12718	0.155
SL50-25	38320.42800	4314.90041	8.88095	0.006
SL25-0	478702.27200	5887.08579	81.31396	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 9

MANOVA Summary for the Effect of Speech Intelligibility on the Time Required to Kill Multiple Targets

Bartlett Test of Sphericity: 46.51534 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.91970	74.44877	4.00	26.00	0.000
Hotellings	11.45366	74.44877	4.00	26.00	0.000
Wilks	0.08030	74.44877	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	9072.36300	2190.57610	4.14154	0.051
SL100-50	209.36969	12.77783	16.38539	0.000
SL75-50	14834.08033	5973.28516	2.48340	0.126
SL50-25	30592.13333	4398.59264	6.95498	0.013
SL25-0	493955.00833	5485.78213	90.04277	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 10

MANOVA Summary for the Effect of Speech Intelligibility on Overall Mission Time

Bartlett Test of Sphericity: 49.19724 with 6 DF

Significance: 0.000

Multivariate Tests of Significance (S=1, M=1, N=12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.86467	41.53117	4.00	26.00	0.000
Hotellings	6.38941	41.53117	4.00	26.00	0.000
Wilks	0.13533	41.53117	4.00	26.00	0.000

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical MS	Error MS	F	Significance of F
SL100-75	328.55061	59.65585	5.50743	0.026
SL75-50	242.08161	176.61844	1.37065	0.251
SL50-25	1753.22785	176.41848	9.93789	0.004
SL25-0	6599.94336	201.17402	32.80714	0.000

[a]SL100, 2L75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Table 11

MANOVA Summary for the Effect of Speech Intelligibility on the Number of Times a Friendly Crew was Killed by Enemy Fire

Multivariate Tests of Significance (S-1, M-1, N-12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.68896	14.39749	4.00	26.00	0.000
Hotellings	2.21500	14.39749	4.00	26.00	0.000
Wilks	0.31104	14.39749	4.00	26.00	0.000
Roys	0.68896				

Note. F statistics are exact.

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical SS[b]	Error SS	Hypothetical MS	Error MS	F	Significance of F
SL100-75	0.09633	0.51367	0.09633	0.01771	5.43868	0.027
SL75-50	0.00833	1.00167	0.00833	0.03454	0.24126	0.627
SL50-25	0.24300	1.14700	0.24300	0.03955	6.14385	0.019
SL25-0	0.07500	1.91500	0.07500	0.06603	1.13577	0.295

[a]SL100, SL75, SL50, SL25, SL0 indicate percent of speech intelligibility.
[b]SS = Sum of squares

Table 12

MANOVA Summary for the Effect of Speech Intelligibility on Communication Errors

Multivariate Tests of Significance (S-1, M-1, N-12)

Test Name	Value	Exact F	Hypothetical DF	Error DF	Significance of F
Pillais	0.83650	33.25475	4.00	26.00	0.000
Hotellings	5.11612	33.25475	4.00	26.00	0.000
Wilks	0.16350	33.25475	4.00	26.00	0.000
Roys	0.83650				

Note. F statistics are exact.

Univariate F-tests with (1,29) DF

Variable[a]	Hypothetical SS	Error MS	F	Significance of F
SL100-75	0.26133	0.17720	1.47483	0.234
SL100-50	0.32033	0.06930	4.62249	0.040
SL75-50	0.00300	0.23886	0.01256	0.912
SL50-25	7.10533	0.42533	16.70533	0.000
SL25-0	67.50000	1.49241	45.22874	0.000

[a]SL100, SL75, SL50, SL25, SL0 indicate percent of speech intelligibility.

Regression

A regression analysis was performed on the time required to identify a target during a multiple target mission. Fire time and kill time were not examined since they were constant across intelligibility. The purpose of the regression was to establish which variables accounted for the majority of the variance. The slope that was derived can be used to predict identification time as a function of intelligibility and will be a part of the Human Engineering Laboratory (HEL) performance model (see Discussion section).

Table 13 lists the results of the regression analysis. Speech intelligibility level was determined to account for approximately 19% of the difference in performance. Three of the targets accounted for an additional 5% of the variance. Crew, target type, and target number accounted for less than 1% of the variance.

DISCUSSION

The purpose of this study was to evaluate and quantify changes in crew performance as a function of speech intelligibility during gunnery exercises. The results of this study have shown that mission performance for both single and multiple targets can vary as a function of intelligibility and are quantifiable.

The specific measures used to evaluate performance as a function of speech intelligibility fell into four general categories:

1. Mission time
    a. Time to identify the target
    b. Time to fire upon the target
    c. Time to kill the target
    d. Time to accomplish the mission
2. Mission completion
    a. Percent of targets identified
    b. Percent of targets killed
3. Mission errors
    a. Percent of crew killed
    b. Percent of times wrong target was killed
    c. Percent of communication errors
4. Gunner accuracy
    a. Number of rounds required to kill a target
    b. Aiming error

Table 13
Regression Summary

Step	Variable entered	Number included	Partial R**2	R**2	C(P)	F	PROB>F
1	SILL	1	0.1932	0.1932	451.747	538.1872	0.0001
2	TARGN14	2	0.0140	0.2072	406.839	39.7623	0.0001
3	TARGN2	3	0.0262	0.2334	321.279	76.7213	0.0001
4	TARGN3	4	0.0120	0.2454	283.112	35.7395	0.0001
5	TARGN13	5	0.0195	0.2649	219.819	59.6126	0.0001
6	TARGN8	6	0.0121	0.2770	181.317	37.581	0.0001
7	TARGN4	7	0.0065	0.2835	161.559	20.3634	0.0001
8	CREW13	8	0.0064	0.2899	142.278	20.0865	0.0001
9	CREW17	9	0.0071	0.2970	120.660	22.5062	0.0001
10	CREW23	10	0.0055	0.3024	104.365	17.5620	0.0001
11	CREW5	11	0.0046	0.3070	90.967	14.8737	0.0001
12	CREW10	12	0.0034	0.3105	81.559	11.0686	0.0009
13	CREW16	13	0.0023	0.3128	75.722	7.6261	0.0058
14	CREW3	14	0.0031	0.3159	67.465	10.0223	0.0016
15	CREW27	15	0.0021	0.3180	62.410	6.9111	0.0086
16	CREW19	16	0.0025	0.3205	55.968	8.2972	0.0040
17	TARGN9	17	0.0020	0.3225	51.208	6.6612	0.0099
18	CREW2	18	0.0019	0.3245	46.759	6.3699	0.0117
19	CREW29	19	0.0020	0.3265	41.908	6.7840	0.0093
20	CREW7	20	0.0018	0.3283	37.800	6.0624	0.0139
21	CREW14	21	0.0020	0.3303	33.117	6.6494	0.0100
22	TARGN5	22	0.0014	0.3317	30.563	4.5393	0.0332
23	TARG2	23	0.0017	0.3334	27.015	5.5407	0.0187
24	CREW15	24	0.0012	0.3345	25.056	3.9585	0.0468
25	CREW4	25	0.0013	0.3358	22.839	4.2231	0.0400
26	CREW6	26	0.0009	0.3367	21.743	3.1036	0.0783
27	TARGN10	27	0.0007	0.3374	21.343	2.4065	0.1210
28	SIL	28	0.0005	0.3379	21.666	1.6828	0.1947
29	CREW18	29	0.0005	0.3384	22.042	1.6297	0.2019
30	CREW28	30	0.0005	0.3390	22.279	1.7703	0.1835
31	CREW21	31	0.0004	0.3394	22.824	1.4606	0.2270
32	TARGORD	32	0.0002	0.3396	24.030	0.7972	0.3720
33	CREW22	33	0.0002	0.3399	25.256	0.7770	0.3781
34	CREW25	34	0.0002	0.3400	26.620	0.6383	0.4244
35	CREW9	35	0.0002	0.3402	27.971	0.6520	0.4195

Mission Time

The data of Figure 4 indicate that for the particular gunnery scenarios studied in this experiment, the greatest contributor to the time taken to perform a mission, as a function of intelligibility, was the gunner's difficulty in understanding which target to identify. Once the target was identified, the time to fire upon and kill the targets remained fairly constant since limited additional communication was required.

A second trend that was observed was that all mission times showed minimal variance and were fairly constant until around 25% intelligibility. It should be noted that these results were only for those crews able to complete the assigned mission since these times could not be obtained for crews that did not complete the mission. The effect of these crews is reflected under mission completion and is shown as the percent of enemy targets identified, and killed (see Figures 7 and 8).

Mission Completion

The percent mission completion also displayed significant decreases in ability. Figures 7 and 8 show that the number of targets identified were reduced from 98% to 68% as speech intelligibility was progressively reduced. Also, as would be expected, the number of enemy targets killed was further reduced in a compounding manner from 94% to 41%.

Mission Errors

Mission errors also varied as a function of speech intelligibility. The number of crews killed by enemy fire was more linear, although three groupings occurred which tend to support the above observation. The 7% killed at 93.5% intelligibility was significantly different from the 13% and 14% killed at 73.6 and 52.1%, respectively. All three of these were significantly less than the 23% and 28% killed at 26.3 and 7.1% intelligibility (see Figure 9). Figure 10 displays the percent of time the wrong target was shot. The 100%, 75%, and 50% conditions were not significantly different. The analysis found a significant difference between the 50%, 25%, and 0% conditions. Communication errors stayed fairly constant through 52.1% intelligibility and then quadrupled at 26.3% intelligibility to 9.4% and then quadrupled again at 7.1% intelligibility to 37.3% (see Figure 11).

Gunner Accuracy

Gunner accuracy did not seem to respond to changes in intelligibility (see Figure 12). This is probably because of the high level of training and lack of communication required in aiming and firing tasks.

Normally, the crews were able to kill targets with a single round (see Figure 13), but as intelligibility decreased, the percentage of time a single round was required to kill a target decreased from 90% to 62%. These data

also show that there was a corresponding increase in the number of times that no rounds were fired and in the number of times that two rounds were required to kill a target.

CONCLUSION

This study marks a first attempt to quantify the effect of speech intelligibility upon both work load and performance of a military task. The tasks selected for this study required little communication and used standardized phrases. The listener (usually the gunner) had a limited number of targets from which to select (only four targets were presented at a time) and a limited type of ammunition available (only three types of rounds were available). Also, the crew could only move the vehicle forward over the berm and back to their concealed location after engaging the enemy; they could not navigate over the terrain to their front. In addition, several clues were available to the gunner that assisted in determining the correct target. It is for these reasons that performance was high even with poor communication conditions.

This study provides valuable first insights into performance effects and accurately quantifies a number of dependent performance variables that are affected by speech intelligibility under the conditions of this study.

Because the performance data in this study are a function of the specific experimental task, they should be generalized to other situations very cautiously. However, it is reasonable to contend that a similar pattern of performance errors will probably accompany communications difficulties in similar tasks. Additional studies are needed to establish a more substantial data base before making generalizations to different situations or applying these results to MIL-STD-1472.

The results of this study will serve as a first step in determining those speech intelligibility levels that need to be specified for present and future weapon system. These data are also applicable for war gaming where they may provide the operations analysts with realistic results for these given conditions and may provide quantifiable performance measures.

Other applications would be in the area of training and job qualification. Mission times and error rates measured at a given level of degraded intelligibility may be a more sensitive indication of the degree of training achieved by an individual. It may be possible to match a student's mission time at a given level of intelligibility with a certain skill level. It may also be possible to match an operator who has a hearing loss, for example, with an established base line of expertise.

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APPENDIX A

SCENARIOS

SCENARIOS

(Note. The circle to the left of each command was used by the experimenter to record whether an idea was correctly transmitted from the commander to the gunner.)

Engagement 1

GUNNER - SCAN TO THE FRONT
(_) (_) CLOSE BALLISTIC DOORS, USE GAS
(_) (_) GUNNER - BATTLESIGHT - TRUCK: TRAVERSE (RIGHT, LEFT) - STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) (_) CORRECTION: GUNNER - BATTLESIGHT - CHOPPER
(_) (_) FIRE - FIRE - HEAT

Engagement 2

(_) LAY ON BARN - CHECK DRIFT
GUNNER - SCAN TO THE FRONT
(_) (_) GUNNER - COAX - TROOPS
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) (_) CORRECTION: GUNNER - SABOT - TRUCK
(_) (_) FIRE - FIRE - HEAT

Engagement 3

GUNNER - SCAN TO THE FRONT
(_) GO TIS
(_) (_) GUNNER - SABOT - TRUCK
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT
DRIVER BACK UP
(_) TROOPS TRAVERSE (LEFT, RIGHT) - STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) (_) CORRECTION: GUNNER - HEAT - CHOPPER
(_) (_) FIRE - FIRE - SABOT

Engagement 4

GUNNER - SCAN TO THE FRONT
(_) GO TIS
(_) (_) GUNNER - SABOT - TRUCK
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) FIRE - FIRE - HEAT
DRIVER BACK UP
(_) CHOPPER TRAVERSE (RIGHT, LEFT) - STEADY . . . ON

DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - SABOT

Engagement 5

(_) LAY ON BARN - CHECK DRIFT
GUNNER - SCAN TO THE FRONT
(_) (_) GUNNER - SABOT - CHOPPER
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT
DRIVER BACK UP
(_) TRUCK - TRAVERSE (LEFT, RIGHT) -
STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE

Engagement 6

GUNNER - SCAN TO THE FRONT
(_) GO TIS
(_) (_) GUNNER - COAX - TROOPS
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) (_) CORRECTION: GUNNER - SABOT - TANK
(_) (_) FIRE
DRIVER BACK UP
(_) TRUCK - TRAVERSE (LEFT, RIGHT) -
STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT

Engagement 7

GUNNER - SCAN TO THE FRONT
(_) GO TO MANUAL MODE, USE GAS
(_) (_) GUNNER - BATTLESIGHT - TRUCK
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT
DRIVER BACK UP
(_) TANK - TRAVERSE (LEFT, RIGHT) - STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - SABOT

Engagement 8

GUNNER - SCAN TO THE FRONT
(_) GO TO MANUAL MODE, USE GAS
(_) (_) GUNNER - BATTLESIGHT - TANK
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) CEASE FIRE - FRIENDLY - CONFIRM
DRIVER BACK UP

(_) (_) BATTLESIGHT - TRUCK - TRAVERSE (RIGHT, LEFT)
- STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT

Engagement 9

GUNNER - SCAN TO THE FRONT
(_) GO TO MANUAL MODE, USE GAS
(_) (_) GUNNER - COAX - TROOPS
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) CEASE FIRE - FRIENDLY - CONFIRM
DRIVER BACK UP
(_) (_) BATTLESIGHT - CHOPPER - TRAVERSE (RIGHT, LEFT)
- STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) (_) FIRE - FIRE - HEAT

Engagement 10

GUNNER - SCAN TO THE FRONT
(_) (_) GUNNER CLOSE BALLISTIC DOORS, USE GAS
(_) (_) GUNNER - BATTLESIGHT CHOPPER - TRAVERSE
(RIGHT, LEFT) - STEADY . . . ON
DRIVER MOVE OUT - GUNNER TAKE OVER
(_) FIRE

APPENDIX B

COMMANDER'S INSTRUCTIONS

COMMANDER'S INSTRUCTIONS

To begin each encounter, speak the first command line. You may not speak any succeeding line until you receive a verbal or action response.

At any time the gunner does not respond, responds inappropriately, or if you are asked, repeat the last line or use your own words. If the gunner asks for target information, talk the gunner onto the target.

If you are not in manual mode, do not "MOVE OUT" until the gunner has stated "IDENTIFIED." Do not give "FIRE" command until the gunner has stated "IDENTIFIED."

You may move behind the berm at any point in the engagement to keep from being killed; however, after doing so, you may not issue any command except "DRIVER MOVE UP."

Your mission is to engage targets as outlined without being killed. If you miss a target, re-engage.

During all engagements, it is assumed that your operating controls are inoperative.

Conclude each engagement using normal command, that is, "TARGET," "DRIVER BACK-UP," "BATTLE-CARRY SABOT."

After every engagement, return all switches to normal mode.

Do you understand?

Gunner's Instructions

For all these scenarios, only the gunner can fire. Shoot only those targets at which you are directed to shoot. Follow instructions as they are given to you. Do not second guess; the tank commander (TC) may require actions that seem to go against armor doctrine.

Each encounter will begin with the appearance of four targets. Gunner should always scan front until the TC has issued a command, the gunner must respond to that command or ask for clarification. The TC will wait for the gunner response or for the gunner to state that he has identified a target before issuing the next command. This type of communication will continue through each encounter.

Although each encounter is timed, it will be very difficult to understand one another during some scenarios; do the best that you can. If it becomes impossible to perform your mission, the experiment will automatically proceed to the next encounter.

During this test, keep your helmet fastened at all times. You will hear a wind noise in your helmet and speech will be broken up by static. This is normal for the experiment.

Do you have any questions?

APPENDIX C

SWAT

Mental work load is a concept analogous to physical work load. However, while physical work load can be measured by heart rate, breathing rate, and so forth, measuring mental work load requires the subject to give subjective ratings of the difficulty of the task. One such method is the subjective work load assessment technique (SWAT). SWAT is a rating of subjective mental work load that has been developed and validated by U.S. Air Force Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL). SWAT describes subjective work load as being composed of three dimensions: time, mental effort, and psychological stress.

Time refers to the amount of time pressure an individual experiences when performing a specific task. Mental effort refers to the amount of attention or concentration required to do a specific task. Psychological stress refers to the presence of confusion or frustration that is present in the doing a specific task.

Each of these three primary areas of mental work load (time, effort, stress) has three levels within each area which can be used to rate the task. Level one is associated with the lowest degree of an area, for example, often have spare time (time area). Level three is associated with the highest degree of each area, for example, never have spare time (time area).

With three levels of each area, there is a total of three times three times three, or 27 possible combinations that could describe a work load situation. By putting these combinations on cards and having subjects rank the combination from easiest to most difficult, a profile emerges of that subject. Not only can we discover if that subject is time, effort, or stress conscious, but we can also create an ordinal scale from nominal data.

After rank ordering the 27 cards and obtaining an ordinal scale, a subject completes a task and then rates the mental work load associated with the task as to time, effort and stress: 111, 123, or whatever. Although each scale is individualized by each subject's sort pattern, it is easily seen that a rating of 111 should be near 0, and a rating of 333 should be near 100.

APPENDIX D

DESCRIPTIVE STATISTICS LISTED BY CREW

DESCRIPTIVE STATISTICS LISTED BY CREW

Table D-1

Descriptive Statistical Summary for Single Target Identification Time, Listed by Crew

Crew Number	Mean	SD	Cases
1	12.8160	9.4672	25
2	12.1080	14.2224	25
3	18.5320	20.5578	25
4	15.5680	21.1610	25
5	14.2920	11.2125	25
6	9.9760	10.4459	25
7	14.6520	10.5897	25
8	11.0160	7.8060	25
9	11.7040	8.5296	25
10	8.8960	6.8600	25
11	11.1160	11.7430	25
12	13.3200	12.9223	25
13	6.8120	6.5919	25
14	10.4280	7.4070	25
15	10.8720	11.1023	25
16	8.2240	6.5452	25
17	14.0800	10.7517	25
18	11.7840	9.7526	25
19	8.1280	7.0000	25
20	11.8960	14.7864	25
21	10.1120	8.5902	25
22	10.6720	9.3782	25
23	8.2840	9.0615	25
24	10.7000	11.1001	25
25	11.3720	6.2722	25
26	11.6480	12.4379	25
27	12.4120	8.8325	25
28	14.2960	12.2968	25
29	8.2880	6.2063	25
30	13.6680	5.2893	25
TOTAL	11.5891	11.0210	750

Table D-2

Descriptive Statistical Summary for Single Target Fire Time, Listed by Crew

Crew Number	Mean	SD	Cases
1	20.1920	13.7215	25
2	21.2360	14.3217	25
3	22.5840	14.9073	25
4	18.8920	12.4041	25
5	23.1640	10.9662	25
6	15.5320	9.2302	25
7	22.0920	9.8277	25
8	19.0240	8.5201	25
9	18.4280	8.6336	25
10	15.2040	6.6969	25
11	18.5120	11.2939	25
12	19.8440	11.9827	25
13	12.6480	5.6882	25
14	15.5600	7.0804	25
15	17.0840	12.3460	25
16	15.9960	6.8082	25
17	23.7320	11.6482	25
18	18.3760	10.2073	25
19	14.8160	5.7050	25
20	20.5640	13.1768	25
21	18.6080	8.7692	25
22	18.4240	9.3820	25
23	15.2920	7.4789	25
24	19.4080	12.8864	25
25	19.4000	7.5892	25
26	18.1680	12.2995	25
27	19.6640	7.9095	25
28	22.0520	14.6983	25
29	14.8480	4.2937	25
30	21.5040	7.4193	25
TOTAL	18.6949	10.5088	750

Table D-3

Descriptive Statistical Summary for Single Target Kill Time, Listed by Crew

Crew Number	Mean	SD	Cases
1	21.2080	13.6417	25
2	22.0400	14.3743	25
3	23.3160	14.9522	25
4	19.6680	12.4514	25
5	24.0360	10.8845	25
6	16.2720	9.2517	25
7	22.2760	10.9783	25
8	19.8200	8.6107	25
9	19.4840	8.7813	25
10	15.9440	6.7201	25
11	19.9200	11.4861	25
12	20.7080	12.3773	25
13	13.3880	5.7267	25
14	16.3360	7.0988	25
15	17.8560	12.3940	25
16	16.7560	6.9223	25
17	24.4840	11.6802	25
18	18.0040	8.3431	25
19	16.3560	6.4181	25
20	21.3400	13.2166	25
21	19.3840	8.8157	25
22	19.1640	9.3993	25
23	16.6120	8.0623	25
24	21.3360	13.0987	25
25	20.1400	7.5948	25
26	18.9080	12.3144	25
27	21.4080	8.8668	25
28	22.8160	14.7203	25
29	16.6520	6.8273	25
30	22.2640	7.4432	25
TOTAL	19.5965	10.6205	750

Table D-4

Descriptive Statistical Summary for Multiple Target Identification Time, Listed by Crew

Crew Number	Sum	Mean	SD	Sum of Squares	Cases
1	1275.2	17.0027	12.5613	11676.2195	75
2	1289.6	17.1947	12.2714	11143.4579	75
3	1537.1	20.4947	16.3895	19877.5179	75
4	1451.2	19.3493	14.5357	15635.2675	75
5	1456.4	19.4187	12.3169	11226.2339	75
6	1171.7	15.6227	11.5933	9945.9515	75
7	1431.0	19.0800	10.0925	7537.4600	75
8	1205.8	16.0773	8.4228	5249.7915	75
9	1276.9	17.0253	10.3023	7854.2219	75
10	1113.0	14.8400	10.3870	7983.8200	75
11	1251.8	16.6907	13.1047	12708.1835	75
12	1276.2	17.0160	10.9070	8803.2608	75
13	965.0	12.8667	10.0052	7407.6467	75
14	1074.5	14.3267	8.4751	5315.2267	75
15	1145.2	15.2693	10.7607	8568.6795	75
16	978.8	13.0507	7.7992	4501.2675	75
17	1393.8	18.5840	10.7132	8493.1008	75
18	1128.7	15.0493	8.0495	4794.7875	75
19	1088.2	14.5093	9.6409	6878.1235	75
20	1108.8	14.7840	10.5609	8253.4408	75
21	1039.1	13.8547	9.0193	6019.6859	75
22	1069.8	14.2640	8.1876	4960.7728	75
23	996.7	13.2893	9.6852	6941.4715	75
24	1175.1	15.6680	11.0256	8995.7832	75
25	1145.6	15.2747	6.5457	3170.5819	75
26	1150.4	15.3387	10.0579	7485.9979	75
27	1371.2	18.2827	11.0195	8985.7875	75
28	1242.9	16.5720	11.5401	9854.9512	75
29	1045.7	13.9427	8.2474	5033.4635	75
30	1364.3	18.1907	7.7482	4442.6035	75

Table D-5

Descriptive Statistical Summary for Multiple Target Fire Time, Listed by Crew

Crew Number	Sum	Mean	SD	Sum of Squares	Cases
1	1660.2	22.1360	12.3712	11325.5328	75
2	1914.1	25.5213	12.1945	11004.2859	75
3	1938.7	25.8493	13.3153	13119.9275	75
4	1864.3	24.8573	12.0066	10667.7835	75
5	2024.4	26.9920	12.4648	11497.4552	75
6	1577.1	21.0280	11.3222	9486.1712	75
7	1908.3	25.4440	9.3823	6514.1048	75
8	1739.1	23.1880	8.8458	5790.3392	75
9	1757.5	23.4333	11.2258	9325.3267	75
10	1479.8	19.7307	7.8335	4540.9395	75
11	1728.6	23.0480	13.1488	12793.9672	75
12	1731.3	23.0840	10.4405	8066.3408	75
13	1390.0	18.5333	11.6698	10077.6067	75
14	1526.3	20.3507	8.4436	5275.7875	75
15	1558.9	20.7853	11.3732	9571.7939	75
16	1484.3	19.7907	7.6749	4358.9035	75
17	2086.0	27.8133	10.4435	8071.0067	75
18	1607.0	21.4267	8.4525	5286.8667	75
19	1504.7	20.0627	9.1108	6142.4355	75
20	1665.5	22.2067	9.7065	6971.9867	75
21	1612.5	21.5000	8.7768	5700.3400	75
22	1633.2	21.7760	7.8918	4608.7168	75
23	1413.2	18.8427	8.2388	5022.9235	75
24	1672.5	22.3000	11.1406	9184.3000	75
25	1636.4	21.8187	6.8613	3483.7339	75
26	1650.2	22.0027	10.1117	7566.1995	75
27	1925.2	25.6693	12.4262	11426.3195	75
28	1803.6	24.0480	13.9855	14474.0072	75
29	1524.7	20.3293	7.7311	4422.9355	75
30	1882.8	25.1040	8.7792	5703.5088	75

Table D-6

Descriptive Statistical Summary for Multiple Target Kill Time, Listed by Crew

Crew Number	Sum	Mean	SD	Sum of Squares	Cases
1	1734.2	23.1227	10.8940	8782.2915	75
2	2079.9	27.7320	12.6063	11759.9232	75
3	2015.8	26.8773	12.9108	12334.9515	75
4	1938.6	25.8480	11.9377	10545.7072	75
5	2068.8	27.5840	13.6522	13792.3408	75
6	1650.3	22.0040	11.3255	9491.8288	75
7	2024.7	26.9960	10.4993	8157.3688	75
8	1854.4	24.7253	9.4853	6657.8019	75
9	1892.7	25.2360	12.5288	11615.9128	75
10	1604.3	21.3907	8.3500	5159.4035	75
11	1790.3	23.8707	12.1465	10917.7955	75
12	1829.2	24.3893	10.5397	8220.2915	75
13	1483.1	19.7747	12.3692	11321.7819	75
14	1648.5	21.9800	8.8686	5820.2600	75
15	1655.7	22.0760	11.7464	10210.3368	75
16	1683.7	22.4493	10.4454	8073.8075	75
17	2201.0	29.3467	10.8659	8737.0067	75
18	1690.9	22.5453	8.1471	4911.7259	75
19	1584.7	21.1293	8.6735	5566.9355	75
20	1787.8	23.8373	10.2115	7716.3155	75
21	1769.4	23.5920	10.0957	7542.3752	75
22	1726.1	23.0147	8.0197	4759.3939	75
23	1491.6	19.8880	8.7278	5636.8992	75
24	1913.4	25.5120	12.9684	12445.2392	75
25	1761.3	23.4840	7.7638	4460.4208	75
26	1784.6	23.7947	11.0243	8993.5579	75
27	2087.4	27.8320	12.9088	12331.1032	75
28	1925.0	25.6667	14.8459	16309.6067	75
29	1709.0	22.7867	9.0066	6002.7667	75
30	2039.7	27.1960	10.2854	7828.4688	75

Table D-7

Descriptive Statistical Summary for Overall Mission Time, Listed by Crew

Crew Number	Sum	Mean	SD	Sum of Squares	Cases
1	2252.0	45.0400	20.0233	19645.6200	50
2	2553.8	51.0760	19.8216	19251.8112	50
3	2445.7	48.9140	22.6547	25148.4402	50
4	2367.0	47.3400	19.5875	18799.9200	50
5	2676.0	53.5200	19.3837	18410.5800	50
6	2225.0	44.5000	16.0916	12688.0000	50
7	2380.7	47.6140	20.5577	20708.3602	50
8	2463.0	49.2600	16.4961	13333.9200	50
9	2406.0	48.1200	20.9057	21415.3800	50
10	1940.0	38.8000	13.5168	8952.5000	50
11	2379.8	47.5960	21.8889	23477.0592	50
12	2377.4	47.5480	17.8825	15669.4848	50
13	1979.0	39.5800	16.3620	13118.0800	50
14	2228.0	44.5600	16.7610	13765.6200	50
15	2126.0	42.5200	14.4368	10212.5800	50
16	2130.0	42.6000	16.2409	12924.5000	50
17	2626.0	52.5200	21.7784	23240.5800	50
18	2215.0	44.3000	17.2284	14544.0000	50
19	2181.0	43.6200	16.4123	13198.8800	50
20	2265.0	45.3000	19.1162	17906.0000	50
21	2088.0	41.7600	17.5560	15102.4200	50
22	2328.0	46.5600	15.6698	12031.6200	50
23	1926.0	38.5200	15.2480	11392.5800	50
24	2227.0	44.5400	20.8528	21307.1200	50
25	2389.0	47.7800	17.8603	15630.4800	50
26	2151.0	43.0200	16.4925	13328.0800	50
27	2685.0	53.7000	21.7584	23198.0000	50
28	2153.0	43.0600	17.7874	15503.1200	50
29	2056.0	41.1200	13.1408	8461.3800	50
30	2654.0	53.0800	20.8731	21348.5800	50